PHYSICS 222, Fall 1995
Exam #3, November 16, 1995, 8:00 – 9:30 pm
VERSION A

Instructions:

1. Check that your multiple choice answer sheet ("bubble sheet") is marked "A" on the upper right hand corner of the front side. If it not so marked, call one of the instructors. Also, the version should be marked in question 101 on the back of the answer sheet. Also check the version on page 5.

2. You will need a calculator for some of the questions. If you did not bring a calculator, or if your calculator stops working during the exam, call one of the instructors. We have a limited number of calculators available.

3. This exam contains 12 multiple choice questions (numbered from 25 to 36) worth 3 points each, and 2 write-up problems worth 16 points each. Hence, the total number of available points is 68. Since 65 points is a perfect score, the exam allows for 3 bonus points.

4. This exam has 11 pages. All pages are printed on front and back except for page 7 (last page of multiple choice questions).

5. In marking the multiple choice answer sheet use a number 2 pencil. Do NOT use ink. If you did not bring a pencil, ask for one. Fill in the appropriate circles completely. If you need to change an entry, you must first completely erase your previous entry. We suggest that you also circle the correct answer on the exam sheet.

6. Make sure that your name, student identification number, and section number are filled in at the appropriate places on the computer answer sheet **and at the top of write-up problems 1 and 2**.

7. Correct answers in the write-up problems with little or no work shown will receive little or no credit. Make sure that you use correct style, i.e., your answers should contain the correct units, vector signs for vectors, etc.

8. When you are done with the exam at the end of the period, put everything (computer answer sheet, formula sheet, written problems, scratch paper, and everything else) back into the folder. Give the folder to the TA for your section. You will not receive credit for any material that may be missing from your folder when your TA opens it for sorting after the exam.

9. Ask one of the instructors for assistance, if you have additional questions.

10. Good luck and have a good Thanksgiving break !!!

Stefan Zollner and Joseph Shinar, November 17, 1995.

25. **Constructive** interference of two wave sources occurs,

    (A) if the wavelengths of the two sources are different.
    (B) **if the path difference is a multiple of the wavelength λ.**
    (C) if the phase difference is a multiple of $\pi/2$.
    (D) if the path difference is a **half-integral** multiple of λ.
    (E) if the phase difference is a multiple of π.

26. How far from the central bright spot is the fifth dark fringe of a Young's double slit experiment, if the wavelength λ of the light is 600 nm, the screen is 2.5 m from the slits, and the slits are 0.5 mm apart?

    (A) 0.135 mm.
    (B) **13.5 mm.**
    (C) 33 mm.
    (D) 3.3 mm.
    (E) 135 mm.

27. Water waves of wavelength 2.0 cm in a ripple tank approach a flat barrier with a 4 cm wide opening. What is the **total angular width** of the central beam of diffracted waves (i.e., the angular width between the first lines of destructive interference)?

    (A) $40°$.
    (B) $50°$.
    (C) **$60°$.**
    (D) $20°$.
    (E) $15°$.

28. The polarization of light is related to the fact that light waves are

    (A) compressional shock waves.
    (B) scalar waves.
    (C) longitudinal waves.
    (D) **transverse waves.**
    (E) pressure waves.

29. What is the maximum velocity of a photoelectron emitted from a surface whose work function is 5 eV when illuminated by a light source whose wavelength is 200 nm?

(A) 460 km/s.
(B) **650 km/s.**
(C) 420 km/s.
(D) 550 km/s.
(E) 1480 km/s.

30. The term "Compton effect" is used to describe the scattering of light by an electron at rest. After the collision, the wavelength of the scattered wave is

(A) **greater or equal to the initial wavelength.**
(B) equal to the initial wavelength.
(C) less than or equal to the initial wavelength.
(D) greater or smaller than the initial wavelength, depending on the sign of the scattering angle.
(E) None of the above, since the photon is annihilated by the electron.

31. The peak in the radiation from the sun occurs at about 500 nm. The temperature on the sun's surface is about 5800 K. What is the surface temperature of a red giant star with a peak wavelength of 700 nm?

(A) 2960 K.
(B) 8120 K.
(C) **4140 K.**
(D) 5800 K.
(E) 11370 K.

32. In the third shell (n=3) of the hydrogen atom, the orbital quantum number l can have the following values:

(A) -1, 0, and 1.
(B) 0 and 1.
(C) 1, 2, and 3.
(D) **0, 1, and 2.**
(E) 0.5 and -0.5.

33. The isotope $^{238}_{92}$U decays by emission of an alpha particle $^{4}_{2}$He. The decay product of this reaction is

(A) $^{234}_{94}$Pu.
(B) $^{234}_{90}$**Th.**
(C) $^{237}_{92}$U.
(D) $^{242}_{90}$Th
(E) $^{242}_{94}$Pu.

34. What is the minimum energy a photon needs to have in order to produce an electron-positron pair?

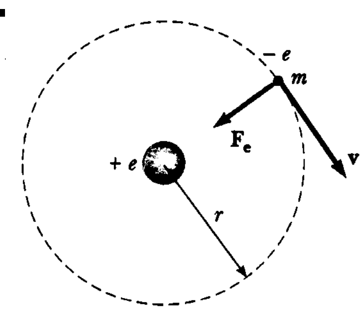
(A) 1.02 eV.
(B) 1.02 keV.
(C) **1.02 MeV.**
(D) 1.02 GeV.
(E) 1.02 TeV.

35. A diver at a depth of 33 feet experiences a gauge pressure of approximately

(A) 0.5 atm.
(B) 3 atm.
(C) 0.3 atm.
(D) 0.2 atm.
(E) **1 atm.**

Problem 1:

In his model for the hydrogen atom, Bohr thought of the electron as a classical particle circling around the nucleus (a proton), much like the moon circles around the earth.



A. If the angular momentum of the electron has its smallest possible value, what is the velocity v (in m/s) of the electron if its distance r from the nucleus is 0.0529 nm (3 points).

Answer: Since the angular momentum L is an integral multiple of $\hbar$ ($L = n\hbar$), the smallest value for L is $\hbar$=h/2π=1.055×10^{-34} Js.
Since $\vec{L} = \vec{r} \times \vec{p}$ and $L = rp = rmv$, the smallest value for v is v=L/mr=2.188×10^{6} m/s.

B. Write down an expression for the **total** energy of the electron as a function of its velocity v and its distance r from the proton (containing both potential and kinetic energy). For the values of v and r from part A., find the kinetic energy, the potential energy, and the total energy of the electron (all in eV). Note: Make sure that all these energies have the **correct sign!** (4 points)

Answer: The total energy E is the sum of the kinetic and potential energy ($E = K + U$), therefore

$$E = K + U = \frac{1}{2}mv^2 - \frac{e^2}{4\pi\epsilon_0 r} \tag{1}$$

The kinetic energy is therefore $K = mv^2/2$=2.181×10^{-18} J=13.61 eV. The potential energy is U=$-e^2/(4\pi\epsilon_0 r)$=-4.361×10^{-19} J=-27.22 eV. The total energy is E=$K+U$=-13.61 eV.

C. A gas (low pressure) consisting of hydrogen atoms is illuminated by a tungsten-halogen lamp emitting a continuous black-body spectrum. What are the three longest wavelengths absorbed from the spectrum by the hydrogen gas? Note: Initially, all electrons are in the ground state (4 points).

Solution: The energy levels of the hydrogen atom are given by the formula $E_n = -E_0/n^2$, where E_0=13.61 eV is the binding energy of the hydrogen atom. In an absorption experiment, all (well, say almost all) electrons are initially in the ground state, therefore only transitions from the ground state (n=1) to an excited state are possible. The photons missing from the spectrum have the energies

$$\Delta E = |E_f - E_1| = hf = \frac{hc}{\lambda} = \left(\frac{1}{1^2} - \frac{1}{n^2}\right) \times 13.61 \text{ eV}. \tag{2}$$

The smallest emitted frequencies and longest wavelengths are therefore
1$\rightarrow$2: hf_1=$\left(\frac{1}{1^2} - \frac{1}{2^2}\right)\times$13.6 eV=10.2 eV λ_1=122 nm
1$\rightarrow$3: hf_2=$\left(\frac{1}{1^2} - \frac{1}{3^2}\right)\times$13.6 eV=12.08 eV λ_2=103 nm
1$\rightarrow$4: hf_3=$\left(\frac{1}{1^2} - \frac{1}{4^2}\right)\times$13.6 eV=12.75 eV λ_3=97.4 nm

D. A tunable laser is used to excite electrons to the third-lowest energy level of the atom. What is the energy of the photons emitted by this laser? How many different wavelengths do you find in the spectrum emitted by the excited hydrogen atoms (including cascade processes)? Explain your answer in complete sentences. Find these wavelengths! (5 points).

Solution: The energy levels of the hydrogen atom are given by the formula $E_n = -E_0/n^2$, where E_0=13.61 eV is the binding energy of the hydrogen atom. The energy of the laser photons needs to be

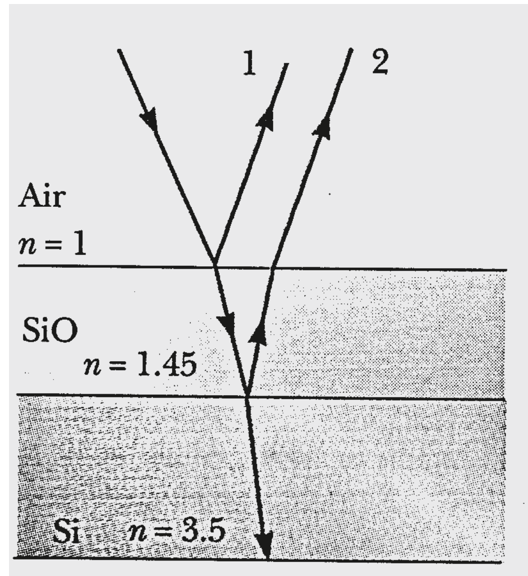
$$\Delta E = |E_3 - E_1| = hf = \frac{hc}{\lambda} = \left(\frac{1}{1^2} - \frac{1}{3^2}\right) \times 13.61 \text{ eV} = 12.08 \text{ eV}. \tag{3}$$

Once the electron are in the third-lowest level (n=3), they can either jump to the ground state (n=1) or to the lowest excited state (n=2). We also have to consider transitions from n=2 back to the ground state (n=1). Therefore, the spectrum will have three lines with the following wavelengths.

$2 \rightarrow 1$: $hf_1 = (\frac{1}{1^2} - \frac{1}{2^2}) \times 13.6$ eV=10.2 eV λ_1=122 nm
$3 \rightarrow 1$: $hf_2 = (\frac{1}{1^2} - \frac{1}{3^2}) \times 13.6$ eV=12.08 eV λ_2=103 nm
$3 \rightarrow 2$: $hf_3 = (\frac{1}{3^2} - \frac{1}{2^2}) \times 13.6$ eV=1.89 eV λ_3=657 nm

Problem 2:

Light from the sun is incident (almost) normally on a solar cell. The solar cell consists of a thick silicon substrate and thin antireflection coating made of silicon oxide (SiO). The refractive index of SiO is about 1.45 over all of the visible spectral range. The refractive index of silicon increases monotonically from n=3.2 at 1000 nm to n=7 at 360 nm.



A. What are the general conditions for the **phase** difference between two waves for (1) constructive and (2) destructive interference? Answer in complete sentences (3 points).

Answer: (1) Two waves interfere constructively if their phase difference is an integral multiple of 2π. (2) They interfere destructively if their phase difference is an odd multiple of π.

B. What do you know **in general** about phase changes at interfaces between media with different refractive indices for **transmitted** or **reflected** beams? Answer in complete sentences (3 points)

Answer: (1) The transmitted beam does not experience a phase shift at an interface. (2) The reflected beam does not have a phase shift, if the beam encounters a medium with a lower refractive index (high to low, phase change no). (3) If the refractive index of the encountered medium is larger than that of the original medium, there is a phase shift of π or 180° (low to high, phase change π).

C. Now refer to the figure and determine an expression for the total **phase** difference between beams (1) and (2) as a function of the SiO film thickness t. Assume normal incidence (5 points).

Solution: The phase difference is $\Delta\phi = 2\pi\Delta r/\lambda = 2\pi \times 2nt/\lambda = 4\pi nt/\lambda$.

D. The efficiency of a solar cell can be increased by minimizing the percentage of reflected light. Determine the minimum thickness of the film that will produce the least reflection at a wavelength of 700 nm (5 points).

Solution: The first minimum occurs, when the phase change is equal to π: $\Delta\phi = 4\pi nt/\lambda = \pi$. This implies that $t = \lambda/4n$=121 nm.